PHM COE Phase I Advisory Board Meeting

Sandia National Laboratories

Structural Health Monitoring Overview

by

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December 6, 2004

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy under contract DE-AC04-94AL85000.

Sandia National Laboratories

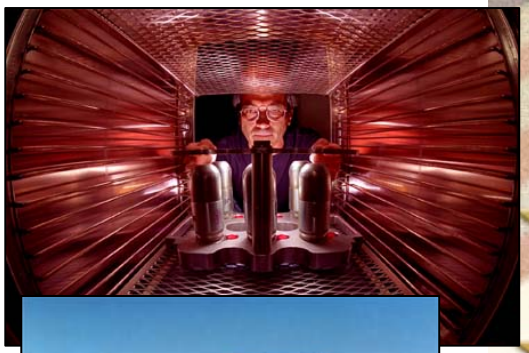
Outline

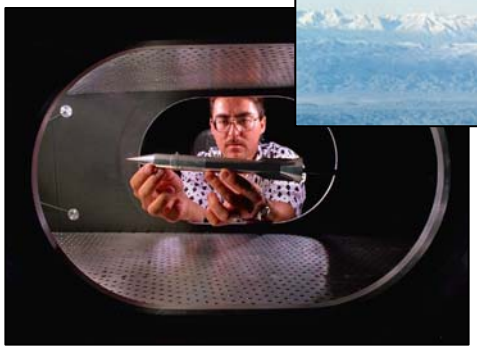
- **Sandia Heritage in System Development**
  - **Performance Assessment of Critical Products**
    - System Integration
    - Physical and Computational Simulation
    - Sensors
  - **Structural Health Monitoring Motivations**
    - 1980’s
    - 1990’s
    - 2000’s
- **New Initiatives**
- **Summary**

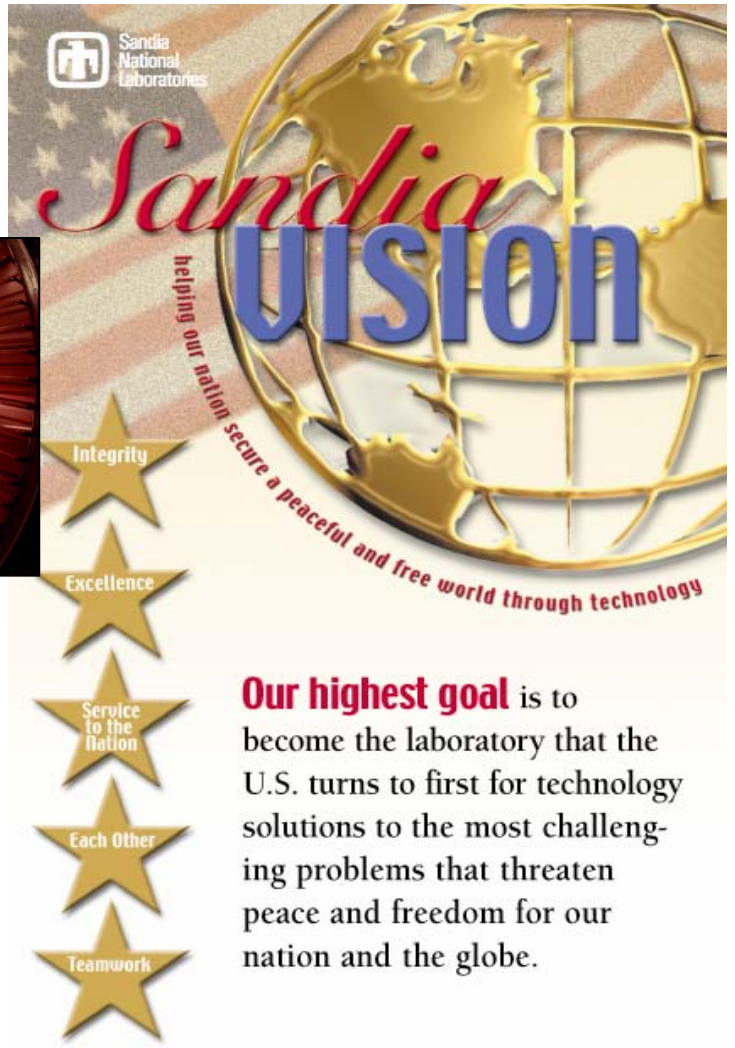
Sandia National Laboratories

Sandia National Laboratories

- **National security laboratory**
- **Primary mission in nuclear weapons**
- **Broader mission in science and technology to meet national needs**







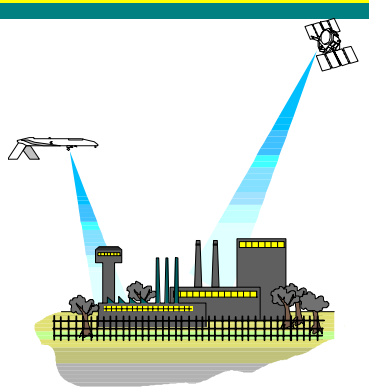
National Laboratories

Sandia is a National Security Laboratory

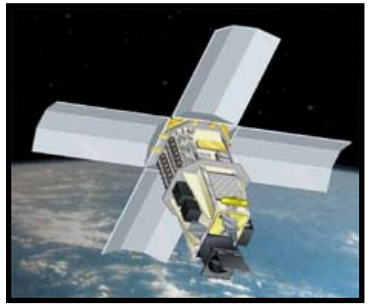
Nuclear Weapons

Safe, Secure,
Reliable Weapons

Nonproliferation & Assessments



Detection



Surveillance

Energy & Infrastructure Assurance

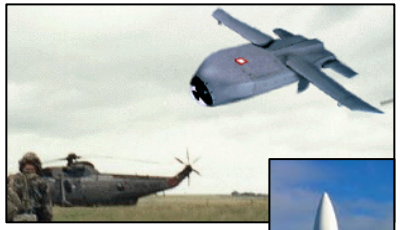
Energy

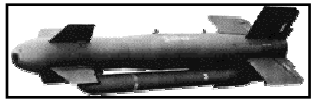
Information

Transportation

Military Technologies and Applications

Advanced Technology
to Protect the Nation





Sandia Motivations in Structural Health Monitoring

Reduce maintenance cost
Optimize service schedule

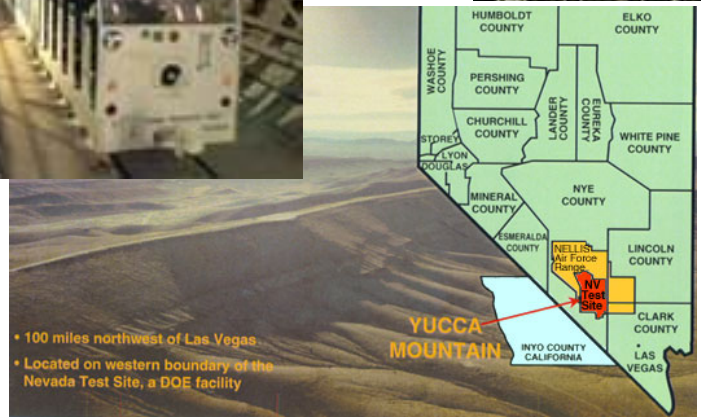
Prevent accidents

Structural Health Monitoring (SHM): a system that monitors structure to detect damage

- reduces maintenance costs
- optimizes service and replacement schedules
- saves lives

Asses integrity of a damaged structure

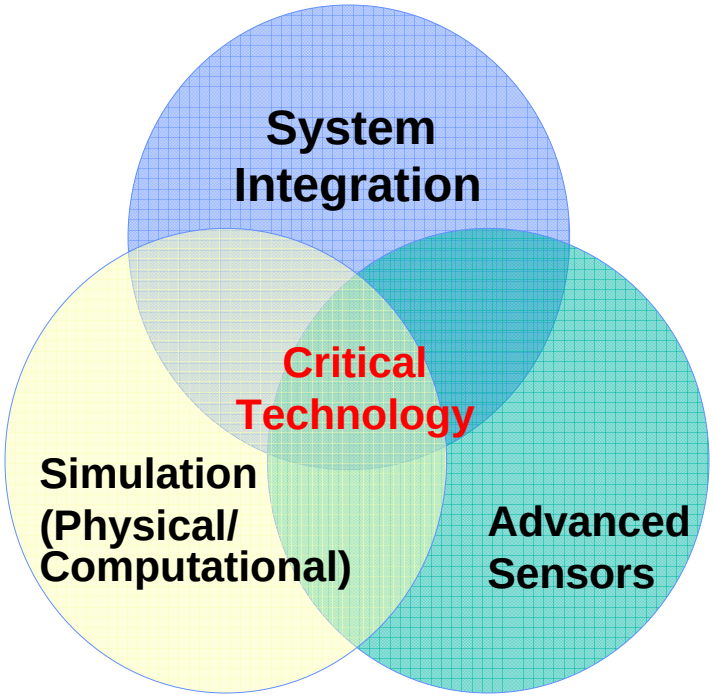
Ensure safety of DOE owned facilities



Sandia National Laboratories

1949 to Present –
R&D for Critical National Security Systems

- **Engineering Non-Nuclear Parts of the Nuclear Weapon Stockpile**
  - Development
  - Safety, Reliability and Security
- **Stockpile Surveillance**
  - Flight Test Program
  - Sampling Program
- **Treaty Verification Technology**
  - Space
  - Ground
- **Energy R&D**
  - Nuclear Material Transportation
  - Pulsed Power Fusion
  - Renewable Energy
- **Advanced Military Technology**
  - SAR
  - Penetrators
- **Development Testing**
  - Full Scale
    - Aboveground (Banned by Treaty)
    - Underground (Banned by Treaty)
  - Radiation
  - Abnormal
  - Environmental Simulation



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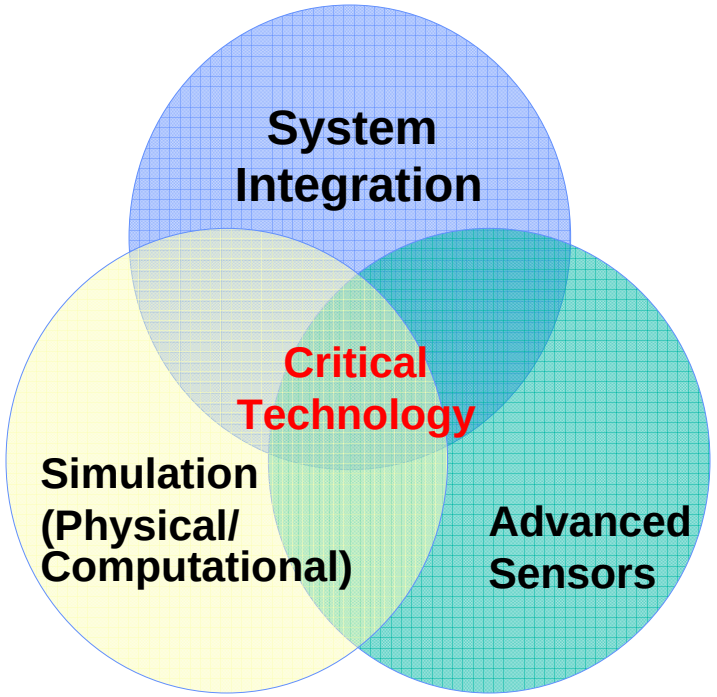
Enduring Stockpile Weapon Systems are Qualified on Evolving Delivery Systems

1980's –
R&D for Critical National Security Systems

- Stockpile Reduction
  - Aging Issue
- Site Security Technology
  - Advanced Sensors
- Transportation Security
  - Mobile Sensors
- Treaty Verification
  - Distributed Sensors
- Experimental Modal Analysis
  - Simplistic Model Validation
  - Hardwired Roving Sensors
  - Limited Sensor Capability
  - Limited Computer Model Capability
  - Operational Testing



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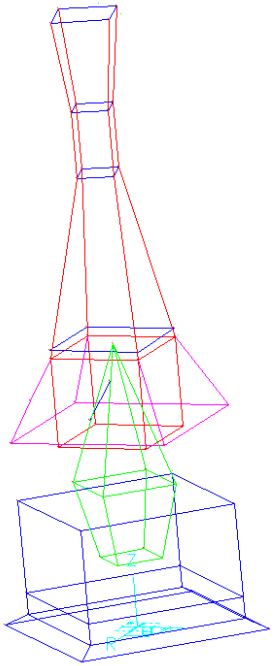
Missile Payload Analysis & Testing



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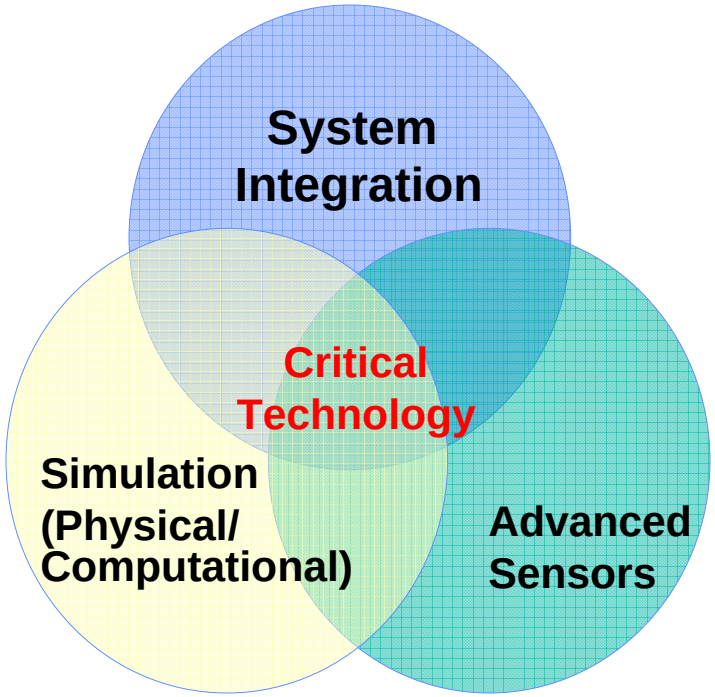
1990's –

R&D for Critical National Security Systems

- **New Focus Areas**
  - **Weapons Complex Consolidation**
  - **Production**
  - **Dismantlement**
  - **Non-Proliferation**
  - **Missile Defense**
  - **Industry Cooperative Research and Development**
  - **ASCI – Accelerated Super Computing Initiative**
  - **End of Underground Testing**

- **Structural Health Monitoring**
  - **Aging Aircraft**
  - **Wind Turbines**
  - **Bridges**
  - **Active Structural Control**
    - Precision Manufacturing
    - Noise Control
    - Space Structures

- **Architectural Surety**
  - **Terrorist Attacks on Civil Infrastructure**
  - **Safety, Reliability and Security of Civil Infrastructure**



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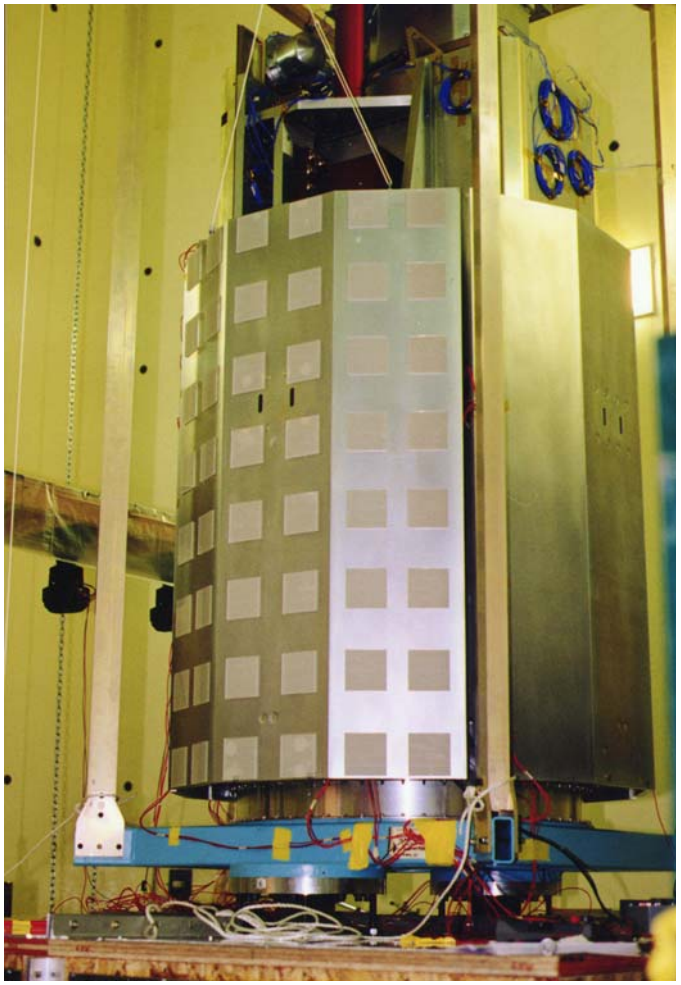
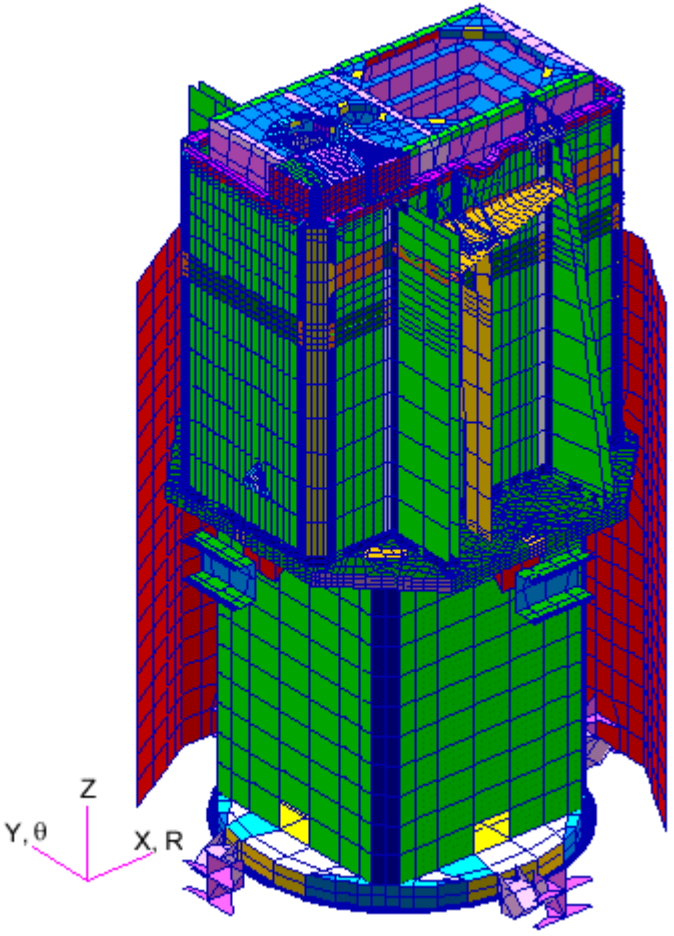
MTI Satellite : Environment Definition, Model Validation / Prediction & Flight Certification (Acoustic and Vibration Testing / NASTRAN & SALINAS FEM



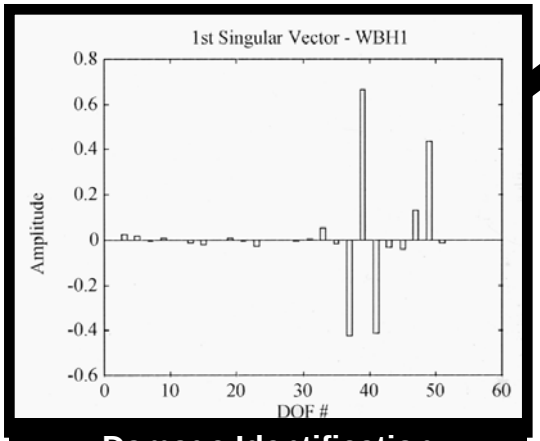


New Health Monitoring Technologies can Monitor Changes in Mass Distribution, Stiffness, Energy Dissipation and Nonlinearity

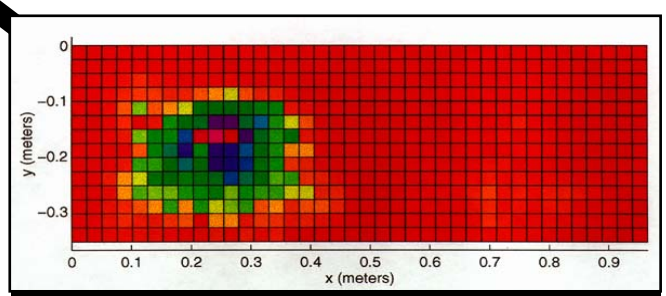
Operational Implementation

Diagnostic Measurement

Structural Health Monitoring Via Dynamics



Damage Identification



Information Condensation

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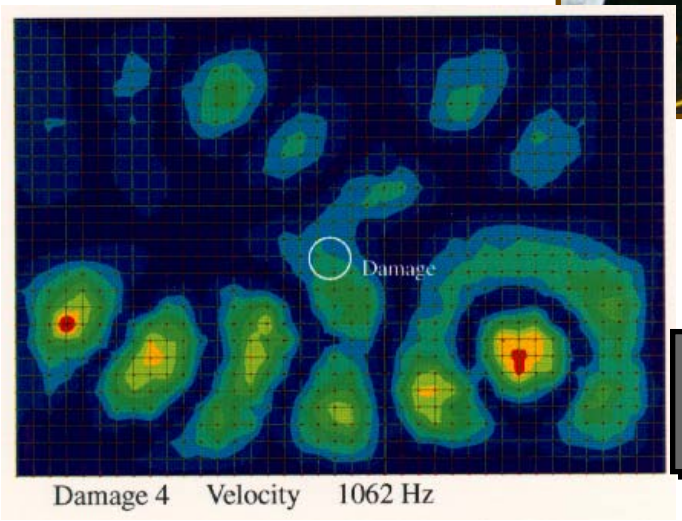
Diagnostic Measurement

- Large areas
- Realistic structures
- High spatial density
- Broad frequency band
- Non-destructive
- Rapid visualization
- Non-contact



Vibration Pattern at 1062 Hz

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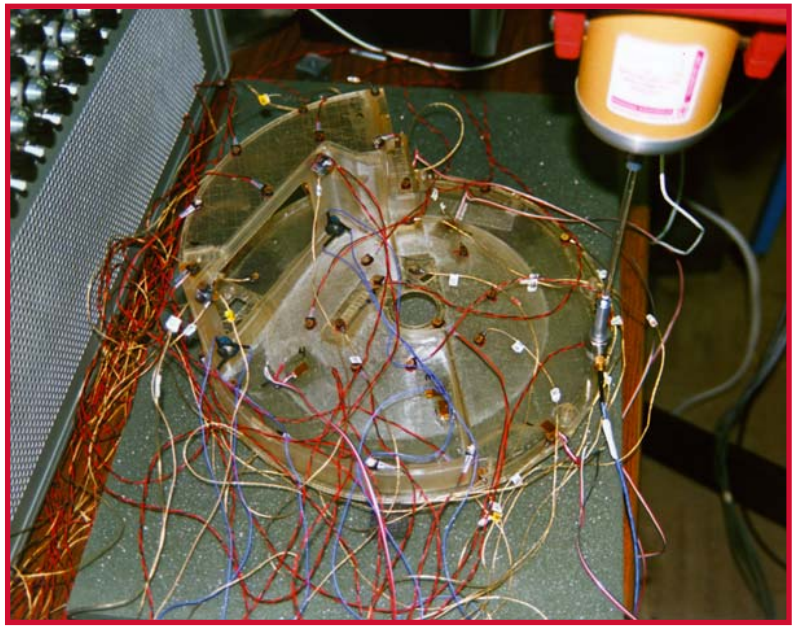
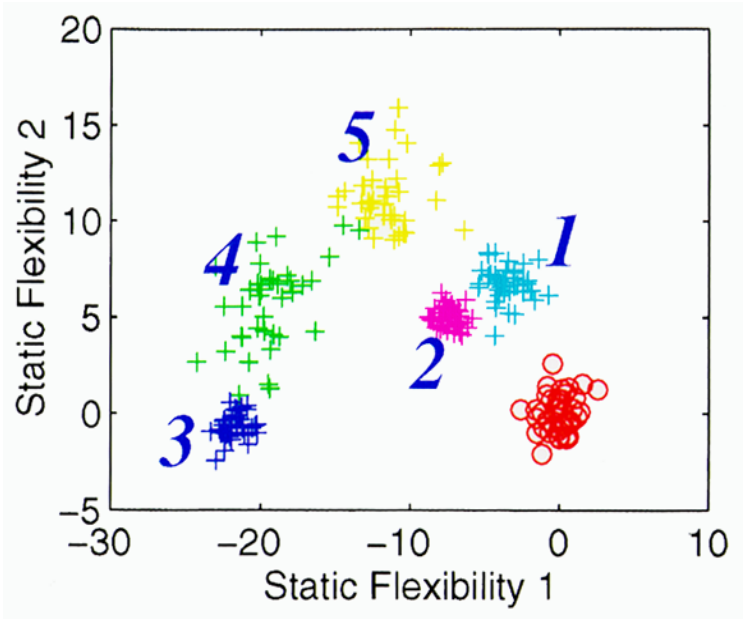
Damage ID with Neural Networks

Cast Metal Bulkhead

- **Rapid Prototyped Part**
- **Induced Damage Study - 5 Damage Cases**
- **Static Flexibility for Information Condensation**
- **Probabilistic Neural Network for Damage ID**





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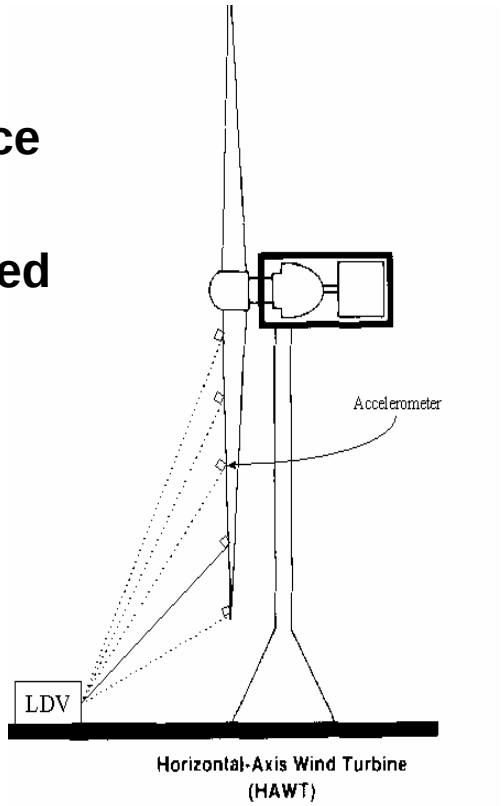
Wind Turbine Structural Health Monitoring

- Testing Performed on HAWT
- Assess LDV system performance in the field
- Assess ability to detect simulated damage
- Assess measures of health monitoring for turbine blades



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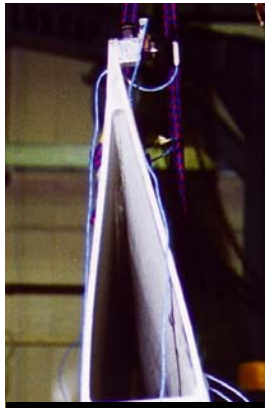
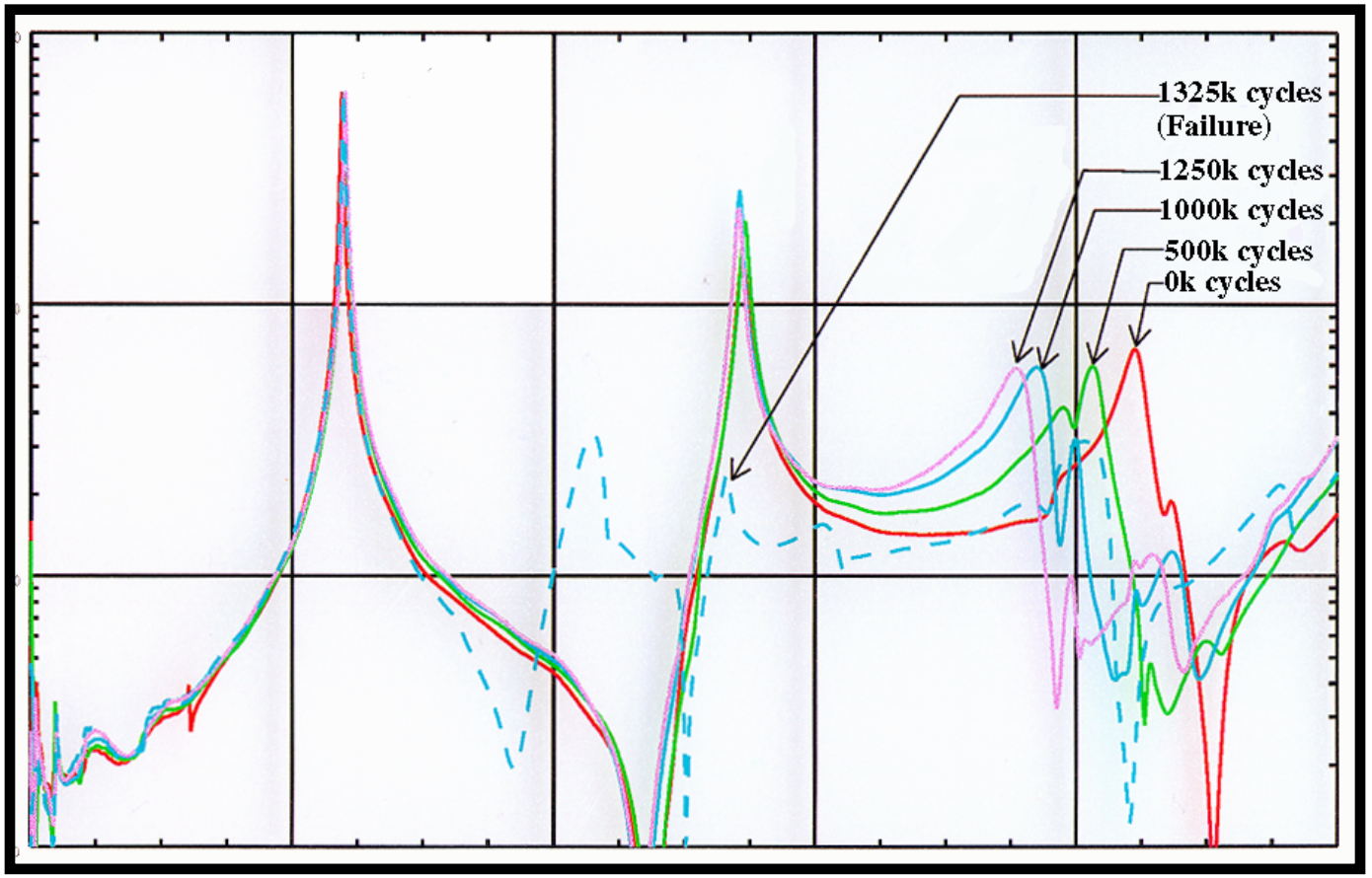
Damage Accumulation Testing of a Wind Turbine Blade



Before

After



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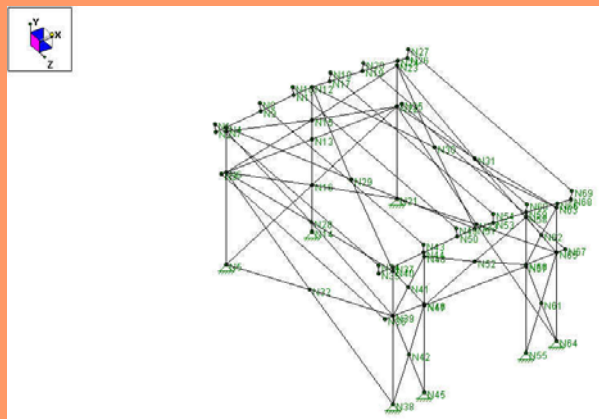
Model and Measure Loads and Responses

Severe Storm Loss Prevention



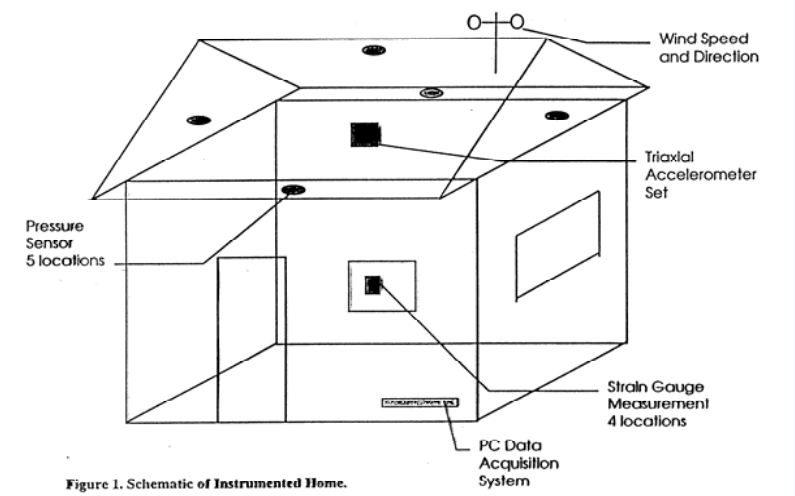
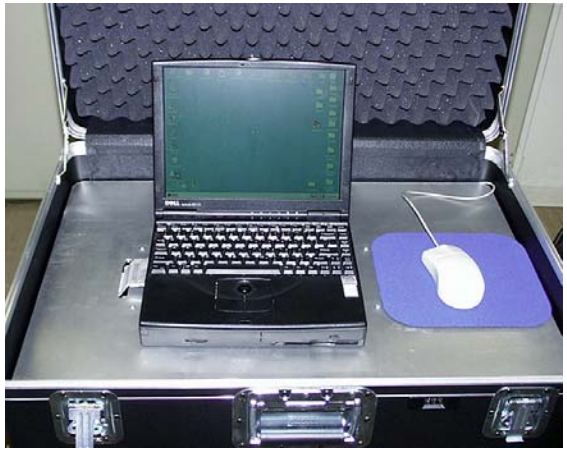
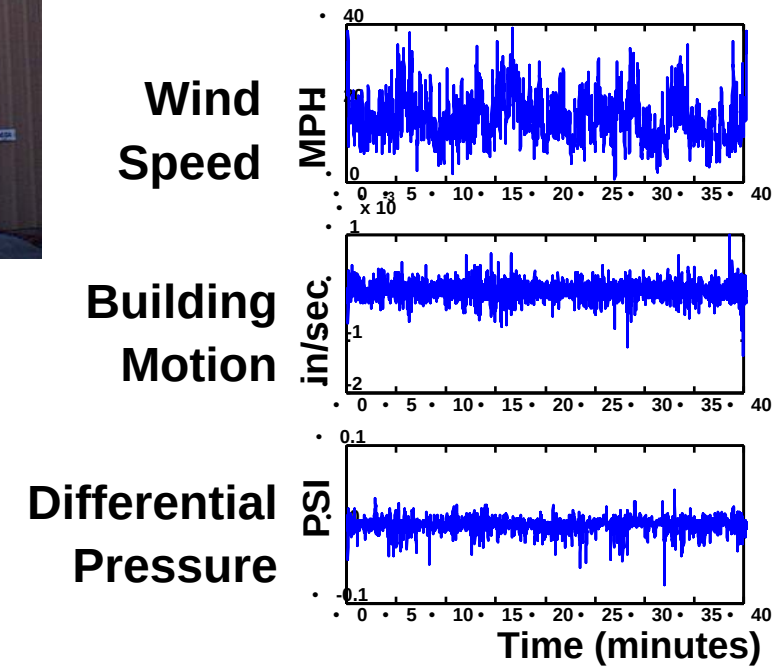


Figure 1. Schematic of Instrumented Home.

Autonomous Severe Event Recorder (ASER)



Correlate Building Excitation and Response



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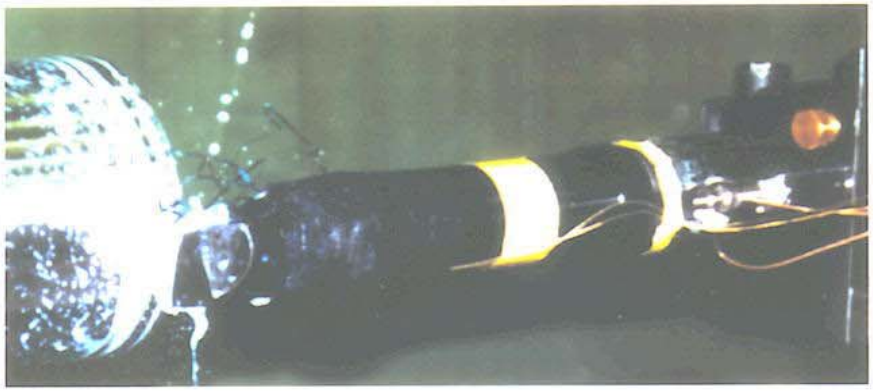
Cutting Test Overview

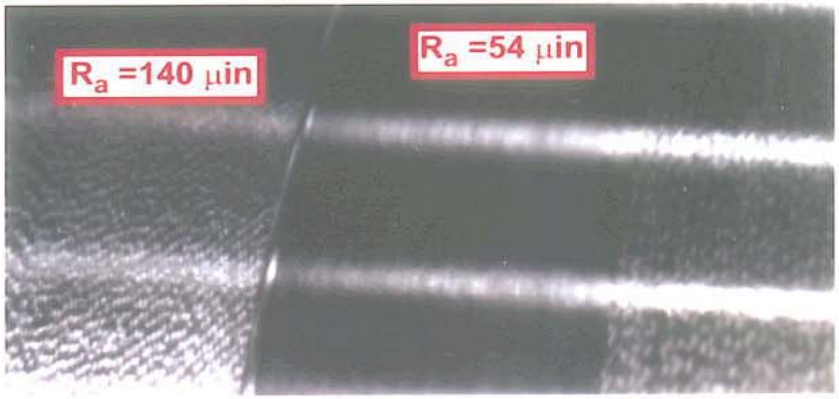
Sandia National Laboratories

Structural Dynamics and Vibration Control Department

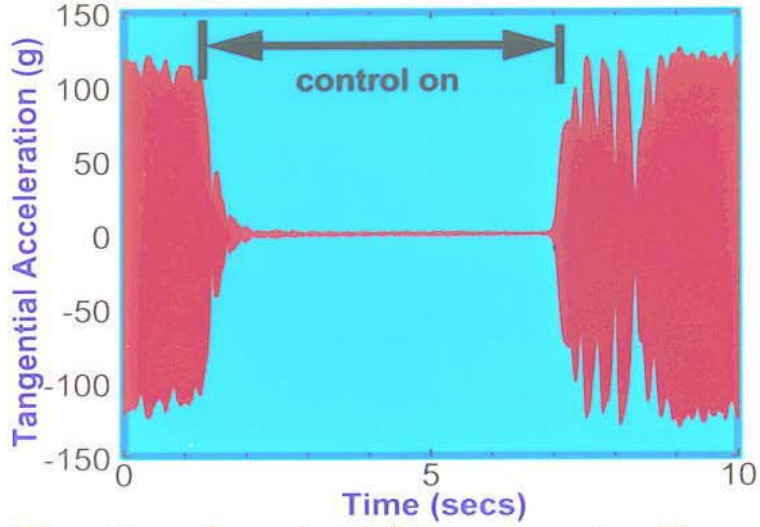
Sandia's Binns & Barry Lathe



L/D=6, 127 RPM, 0.01", 0.0045"/rev



Workpiece Surface Roughness



Chatter Control Demonstration

Smart Materials & Structures Development

Sandia National Laboratories

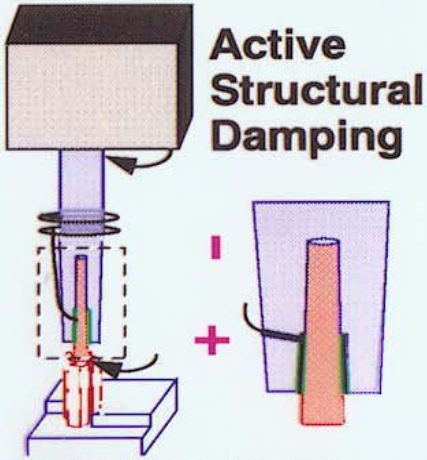
Structural Dynamics and Vibration Control Department

Problem: Excess Flexibility, Resonant Vibration, Unacceptable Transient Dynamic Response, Control Structure Interaction and sudden Failures in Mechanical / Structural Systems

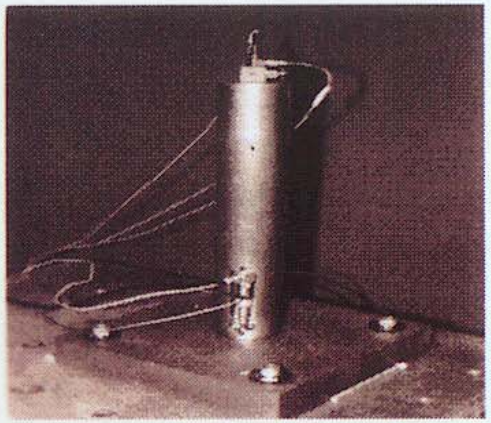
Importance: Performance requirements of new mechanical / structural systems (e.g. weapon components, manufacturing and commercial systems, etc.) demand higher speeds, agility, reliability and more precise operation while also reducing weight / mass and lower energy requirements and cost.

Activities: Developing Vibration, Shape and Position Control in light weight structures using P/E, ER/MR Fluids, SMA materials.

Advanced Machine Tools



ER / MR Fluids



Embedded P/E Actuator

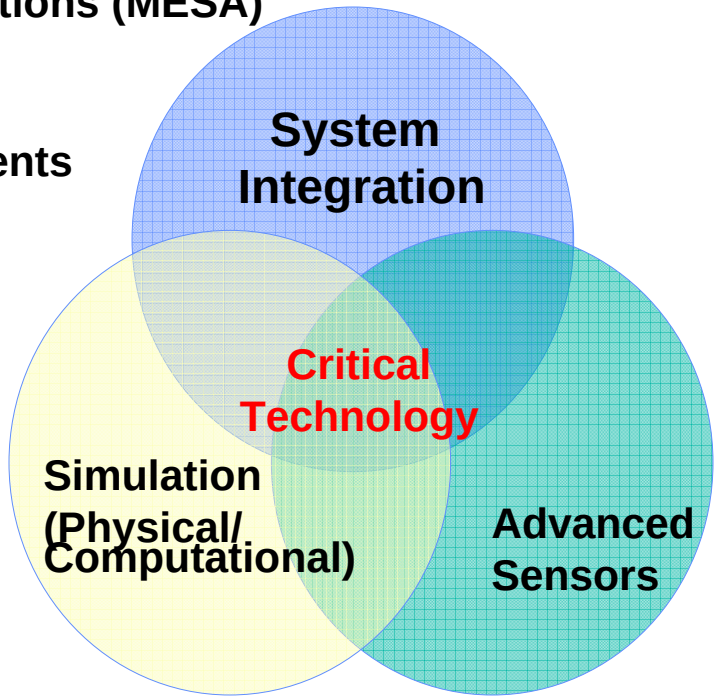
10/30/95

/u12/cabruen/viewgraphs/Smart-Matls-Overview

2000's –
R&D for Critical National Security Systems

- **Weapon System Life Extension Programs**
  - ASC Teraflop Computing
  - Massively Parallel Engineering Codes
  - Experimental Model Validation
  - Uncertainty Quantification
  - Microsystems and Engineering Sciences Applications (MESA)
    - MEMS Development
    - Nano-technology
  - Embedded Sensors for Sandia Weapon Components
    - In-situ Reliability Assessment - Aging
    - Model Validation
    - Manufacturing Process Control

- **Homeland Security**
  - Massively Distributed Sensor Networks
  - Self-powered Sensors
  - Wireless Smart Sensors



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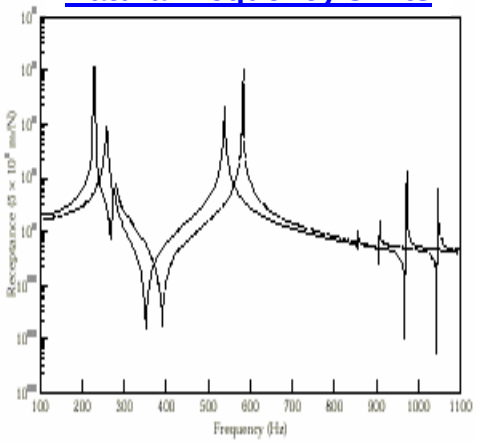
Current SHM Limitations

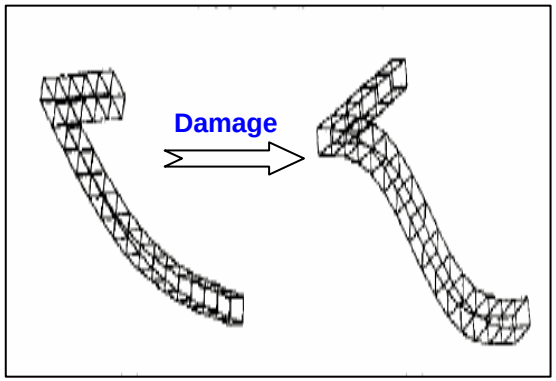
Dynamic Response Methods

- **Based on changes in vibration signature**
- ***Limitations***
  - –Low level of sensitivity to small cracks
  - –Requires great number of sensors to be effective
  - –Expensive

Natural frequency shifts



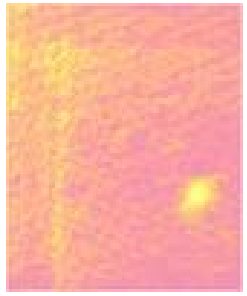
Mode shapes changes



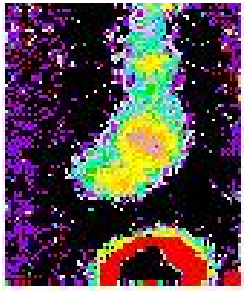
Non-Destructive Evaluation (NDE)

- **Based on wave interruption / reflection**
  - Ultrasonic techniques
  - Acoustic emissions
  - Radiography
  - Thermography
  - Laser holography

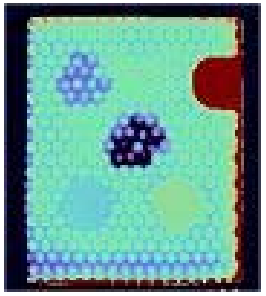
Impact Damage



Steel Pipe Erosion



Multiple Flaws



- ***Limitations***
  - Require local inspections
  - Sophisticated equipment
  - Structure disassembly

SHM functions imbedded in conventional materials

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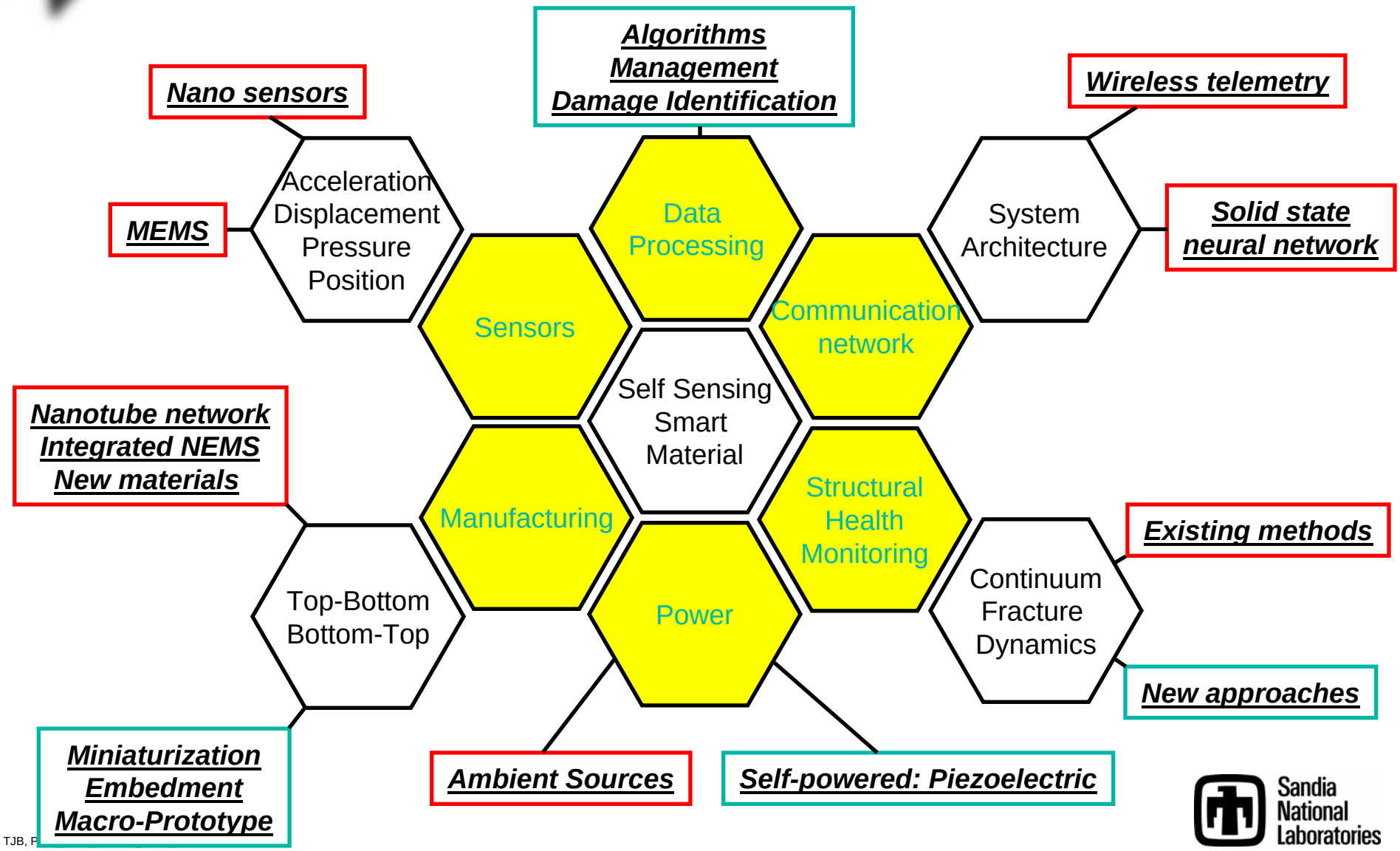
What's been touched… and what's still remains…



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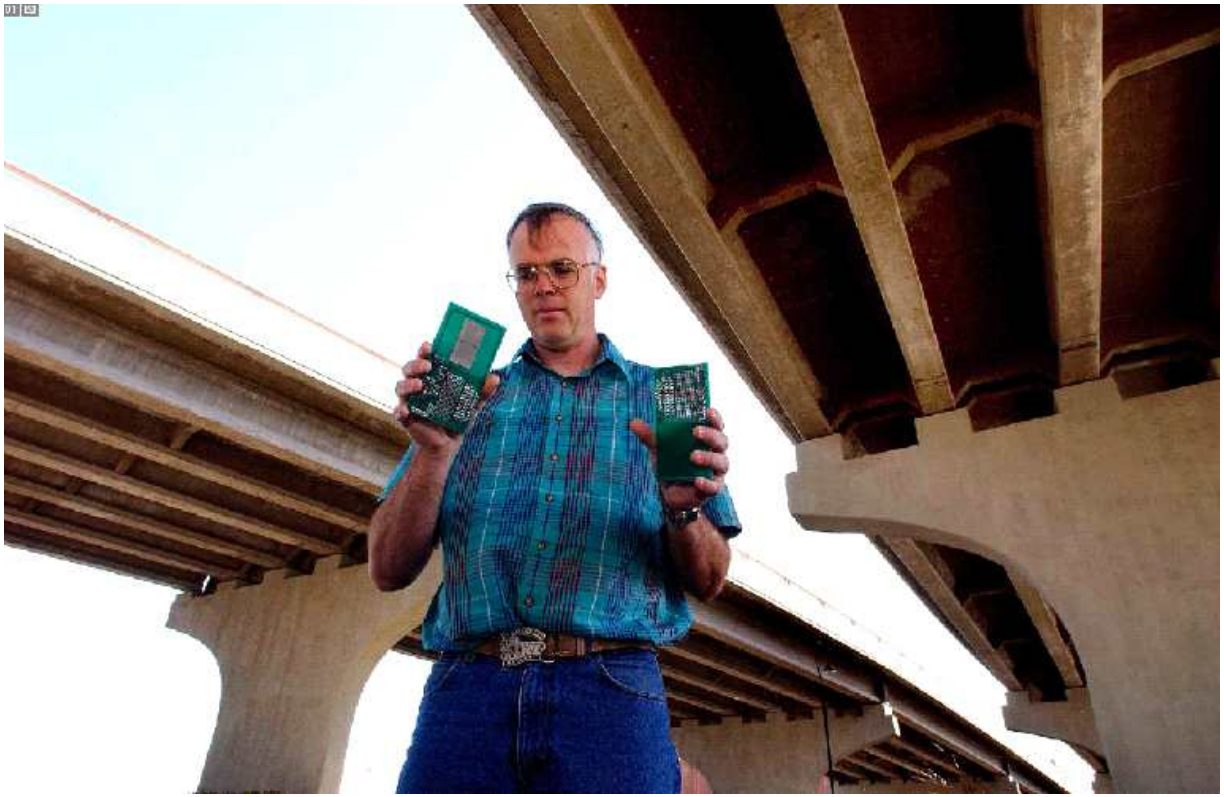
Information Integration Possible on Massive Scale Using Pervasive Sensors and Wireless Data Fusion



Demonstrated the feasibility of a wireless, battery-free, vibration-powered sensor that could help keep tabs on the structural health of buildings and bridges.

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Embedded Neutron Generator Microsensor

Analog Devices MEMS 2-axis accelerometer, 4 x 4 x 1.45 mm

Problem Description:

Create an embedded neutron generator (NG) health microsensor. A truly disruptive technology for neutron tube design, manufacturing and surveillance would be to embed health sensors into operational components.

Proposed Work:

- Develop formal method for organization
- Sample information available for key properties, process issues, and aging concerns.
- Identify detection methods.
- Prioritize and develop roadmap.

Applications:

- Enhance the nuclear weapon mission at Sandia National Labs and national security mission at DOE.
- Potential improvements that would benefit manufacturing, predictive modeling, and surveillance of neutron generators.

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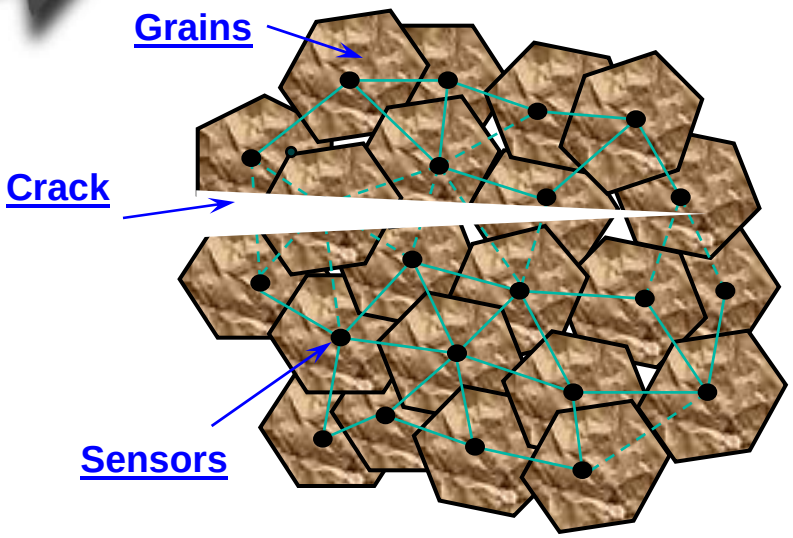
New Smart Materials to Address Issues of Structural Health Monitoring



Technical Approach:

•Assess feasibility of creation new smart materials that will incorporate subgrain nanosize sensors to provide structural health monitoring functions.

Problem Description:

The cornerstone of the existing SHM method's limitations is that the monitoring functions are appended to the conventional materials and structures. We propose creating new structural materials that will incorporate health-monitoring functions as one of their properties, similar to nervous system of a living organism.

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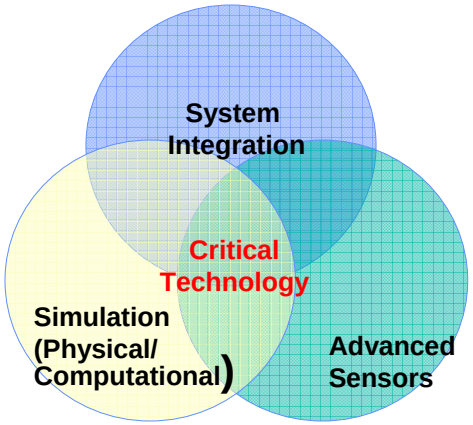
Summary: Structural Health Monitoring of the Future will Integrate Simulation and Sensors

- ***Develop High Resolution Models***
  - –Employ Teraflop Computing Capabilities
  - –Validate Models for Life-cycle Performance Evaluation
- ***Develop Disruptive Sensor Technology***
  - –Real-Time Performance Assessment
  - –Integrate Sensors in Material
  - –Wireless and Self-powered Sensors
- ***Collaborate with Other Agencies***
  - – Simulation and Sensor Technology
  - –Prognostic Algorithms



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Questions?

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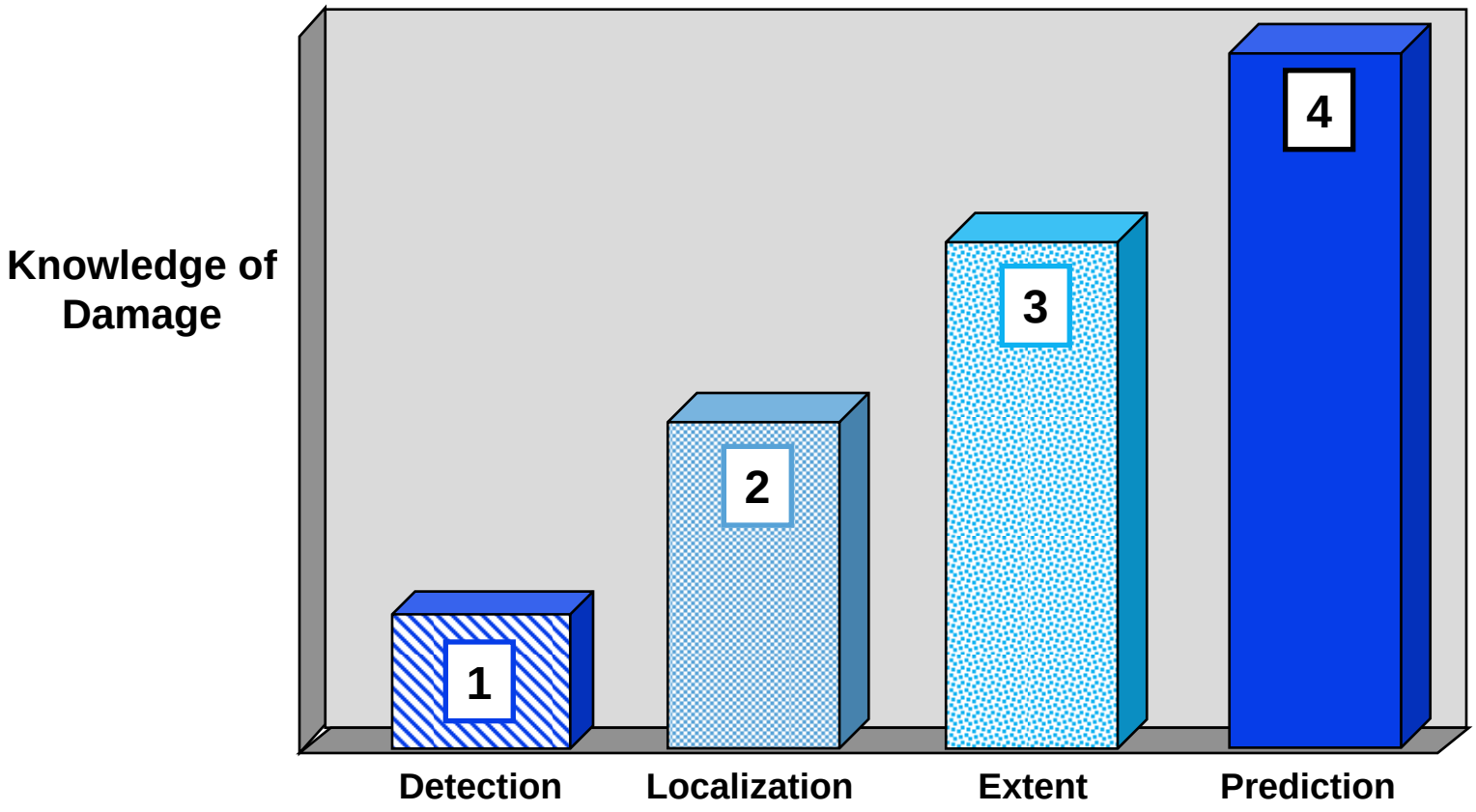
Degrees of Health Monitoring Knowledge



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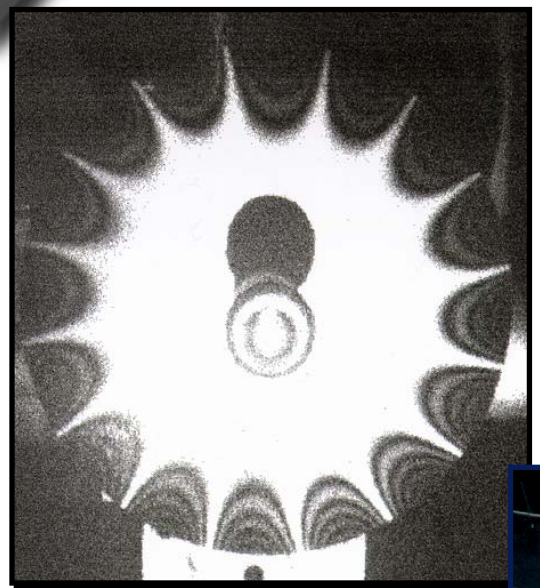
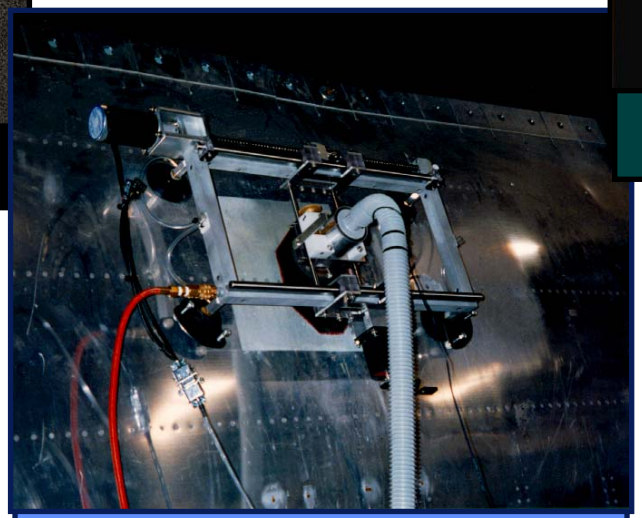
Diagnostic Measurement - Advanced NDE



Laser Holography



Advanced Ultrasonics

Thermography

Sandia National Laboratories